THE EFFECT OF BANDPASS FILTERS ON LASA DETECTION PERFORMANCE

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**Title:** The Effect of Bandpass Filters on LASA Detection Performance  

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**Key Words:** Detection Performance, LASA Noise Level, Noise Filtering

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On-line testing at the SDAC of short-period automatic detection filters 0.9-1.4 Hz, 0.9-1.8 Hz, 0.8-1.8 Hz, and 0.8-2.5 Hz reveals no statistically significant differences in the number of events reaching the LASA summary bulletin. Almost all detection processor detections which do not reach the summary bulletin are due to multiple picks on regional events. Therefore, a substantial lowering of the analyst workload or a substantially lowered threshold
would be possible if a reliable procedure could be developed for flagging
detections due to regional events.

An excellent correlation has been found between the number of events
per hour which reach the summary bulletin, and the hourly noise level.
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On-line testing at the SDAC of short-period automatic detection filters 0.9-1.4 Hz, 0.9-1.8 Hz, 0.8-1.8 Hz, and 0.8-2.5 Hz reveals no statistically significant differences in the number of events reaching the LASA summary bulletin.

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An excellent correlation has been found between the number of events per hour which reach the summary bulletin, and the hourly noise level.
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</tbody>
</table>
INTRODUCTION

Chiburis et al. (1974a,b) evaluated the effects on the detection performance of LASA produced by discarding outer subarrays and by using only unphased subarray sums to form the full array beams. In this study we evaluate the relative detection performance resulting from the use of different bandpass filters in the LASA on-line detection system at the SDAC. Different filters are of interest because the existing 0.9-1.4 Hz filter severely distorts the signal, and may miss some low or high-frequency events. The detection system has recently been described in detail by Chang (1974), and the following description of the LASA detection system is extracted from that report.

A Short Time Average (STA) is computed by rectifying and integrating each filtered array beam over a period of 1.8 seconds, with the average being renewed every 0.6 seconds. Similarly a Long Time Average (LTA) is computed over approximately 16 STA intervals by exponentially weighting the previous LTA value and adding the current STA value. The detection algorithm performs successive tests every 0.6 second.

There are actually two detection algorithms in parallel. The first is the signal-to-noise ratio (S/N) threshold test which determines the size and duration of the signal. When the ratio STA/LTA exceeds the fixed threshold value of N dB Q times out of Q' consecutive tests, the signal switch is declared "ON" for that beam. After the switch activates, the end of signal arrival is declared when the S/N ratio of the beam becomes lower than the

The turn-off threshold of $N'$ dB; and the switch is turned "OFF". The turn-on threshold is set to 10 dB, and the turn-off threshold to 7 dB. The $Q/Q'$ parameter is set to 2/2.

The second detection algorithm is the spatial coherency test. This algorithm determines the consistency of the seismic signal in both azimuth and velocity. When a seismic signal arrives at the array, high STA values may be observed in the neighboring beams. The algorithm seeks the maximum STA beam and checks if the previous maximum was found within the distance of $\Delta U = 2$ beams of the current maximum beam. When this condition is satisfied $P = 3$ consecutive times, the coherency test is satisfied and the arrival is declared to be on the beam with the highest STA value during these $P$ consecutive tests. Then the overall algorithm checks if any of these $P$ beams are "ON". If so, a final "detection" is declared.

The bandpass filter 0.9-1.4 Hz was selected by IBM (1967) on the basis of the signal-to-noise gain achieved in a study of LONGSHOT and a Kamchatka earthquake. The parameter values mentioned above, for $N$, $N'$, $Q$, $Q'$, $\Delta U$, $P$ have also been selected to go along with this filter. Plausible arguments can be made that other parameter values might be suitable for other filters. For example, a broader passband would result in a more stable STA and therefore lower values might be suitable for detection thresholds. Also, a signal passed through a broader passband might not ring so much so that reduction in $Q$ and $Q'$, together with a reduction in $N'$ might be suitable.

Despite these arguments, the parameter values mentioned above were not changed in the course of experimenting with the new bandpass filters in order to minimize difficulties in deciding whether any changes in detection rate were due to parameter changes or to filter changes. It is plausible, therefore, that the performance of the filters other than 0.9-1.4 Hz could be improved by careful selection of detection parameters.

RESULTS

In Figure 1 we see the noise level, number of detection processor (DP) detections, number of events processed by the event processor (EP), and number of events published in the daily event summary bulletin for each day from March 11 through July 25, 1974. Changes in bandpass filter and EP threshold are shown by vertical partition lines.

The noise level is computed as the average of the LTA values reported at detection time for each of the events on the LASA event tape for the day under consideration. Events on the LASA event tape are, almost exclusively, events which appear on the final summary bulletin.

The EP threshold controls the number of events detected by DP which are allowed to be scrutinized by the analyst.

Examination of the noise trace in Figure 1 shows the sudden changes in amplitude which occur with the change in filters. There is no perceptible drift, suggesting that seasonal effects are small, as reported by Dean (1972). The means and differences of the means in terms of $m_b$ are given in Table I for the different time periods.

Row 5 of Table I lists long-term seismic noise values (zero-to-peak) in millimicrons for each filter. The bracketed values represent the change in noise level relative to the broadest filter (Column 4) in $m_b$ units. Row 6 shows corresponding information for rms noise computed over a ten minute sample recorded in June. In this case the data base is common to all filters, and the change in noise levels relative to the broadest filter is about the same as those shown in Row 5 for the broadband noise. This may indicate small seasonal variations in the noise.

Dean, W., 1972, A geophysical evaluation of the short-period LASA/SAAC system, SAAC-5, Teledyne Geotech, Alexandria, Virginia. AD 745101
Figure 1. Noise level, number of detection processor detections, number of events processed by the event processor and number of events published in the daily event summary bulletin for each day from March 11 through July 25, 1974. Changes in bandpass filter and EP threshold are shown by vertical partition lines.
<table>
<thead>
<tr>
<th></th>
<th>Filter Number</th>
<th>1</th>
<th>2*</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Passband</td>
<td>0.9-1.4</td>
<td>0.9-1.8</td>
<td>0.8-1.8</td>
<td>0.8-2.5</td>
</tr>
<tr>
<td>3</td>
<td>Days of 1974 in operation</td>
<td>June 13-</td>
<td>June 26-</td>
<td>Apr 03-</td>
<td>Mar 11-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>June 25</td>
<td>July 25</td>
<td>June 12</td>
<td>Apr 02</td>
</tr>
<tr>
<td></td>
<td></td>
<td>164-176</td>
<td>177-206</td>
<td>93-163</td>
<td>70-92</td>
</tr>
<tr>
<td>4</td>
<td>Total days of operation</td>
<td>13</td>
<td>30</td>
<td>71</td>
<td>22</td>
</tr>
<tr>
<td>5</td>
<td>Long-term zero to peak noise average for all events</td>
<td>0.065</td>
<td>0.097</td>
<td>0.108</td>
<td>0.139</td>
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<tr>
<td></td>
<td></td>
<td>(-0.33)**</td>
<td>(-0.16)**</td>
<td>(-0.11)**</td>
<td></td>
</tr>
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<td>6</td>
<td>10-minute rms noise level, $\mu$</td>
<td>0.056</td>
<td>0.064</td>
<td>0.080</td>
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<tr>
<td></td>
<td></td>
<td>(-0.31)**</td>
<td>(-0.26)**</td>
<td>(-0.16)**</td>
<td></td>
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<tr>
<td>7</td>
<td>Average DP detections per day</td>
<td>199+8</td>
<td>107+5</td>
<td>147+4</td>
<td>84+5</td>
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<tr>
<td>8</td>
<td>EP threshold (dB)</td>
<td>14</td>
<td>14</td>
<td>12</td>
<td>12</td>
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<td>9</td>
<td>Average EP processed events per day</td>
<td>33+6</td>
<td>32+3</td>
<td>54+4</td>
<td>32+3</td>
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<tr>
<td>10</td>
<td>Average daily summary events</td>
<td>26+4</td>
<td>21+2</td>
<td>22+2</td>
<td>20+2</td>
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<tr>
<td></td>
<td></td>
<td>(21.4+7)</td>
<td></td>
<td></td>
<td></td>
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<td>11</td>
<td>Daily summary $\Delta m_b$ if $V&gt;1.0$</td>
<td>0.11</td>
<td>0.02</td>
<td>0.05</td>
<td>0.0</td>
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<tr>
<td></td>
<td></td>
<td>(0.03)</td>
<td></td>
<td></td>
<td></td>
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<td>12</td>
<td>Recurrence curve threshold change 50%</td>
<td>0.14</td>
<td>0.09</td>
<td>0.03</td>
<td>0.0</td>
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<tr>
<td>13</td>
<td>Recurrence curve threshold change 90%</td>
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<td>0.0</td>
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<td>14</td>
<td>EP/DP %</td>
<td>19</td>
<td>30</td>
<td>37</td>
<td>38</td>
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<tr>
<td>15</td>
<td>Summary/DP %</td>
<td>13</td>
<td>20</td>
<td>15</td>
<td>24</td>
</tr>
<tr>
<td>16</td>
<td>Summary/EP %</td>
<td>68</td>
<td>66</td>
<td>41</td>
<td>63</td>
</tr>
</tbody>
</table>

*Day: 194–196 eliminated due to unusual conditions created by Columbian earthquake.

**Change in noise level relative to Column 4 in $m_b$ units.
Also in Figure 1 we see the number of DP and EP events together with the number of summary published events. While the DP and EP traces show sudden jumps at the times when the filter changed, no such change is visible for the summary events trace; and this is verified in Table I where we see that the standard deviation of the summary means are large enough so that one could not say with confidence that any of the means are significantly different from each other. The figure in parenthesis for the average summary events per day with Filter 1 (0.9-1.4 Hz) is obtained by averaging the LASA bulletin from January 1, 1974 through April 30, 1975 with the exceptions of March through July 1974.

In Figure 2 we see (for Filter 3, 0.8-1.8 Hz, the experiment of longest duration) the variation with respect to time of day of the noise, DP detections, EP events, and published summary events. Similar figures are given in the Appendix for the other filters. We see that the noise reaches a minimum at local nighttime, where also there is a maximum in the number of events detected by DP. Surprisingly, however, there is another maximum in detected events between 8 a.m. and 4 p.m. Examination of these signals show that they have the character of local and near-regional events, and that the secondary maximum does not occur on Sundays and holidays. We therefore assume that many of them are due to mining activity.

In every DP detection examined thus far from any hour of the day there have been no indications of a truly "random" false alarm. Regional characteristics predominate. Thus it would seem that a substantial lowering of the analyst workload, together with a corresponding lowering of the detection threshold, would be possible if a regional event rejection algorithm could be devised and implemented.

Figure 2c shows the EP processed events together with the detections which were judged by the analysts to be teleseismic in nature and which were included in the summary bulletin. We see that the EP processed events also show the double maximum. This is reasonable since they were selected from the set of DP detections principally by application of a higher threshold together with automatic elimination of multiple picks of the same event. Corresponding figures for the other filters are included in the Appendix and show corresponding features.
Figure 2. Noise level, number of detection processor detections, number of events processed by the event processor, and number of events in the summary bulletin for each hour of the day for the period April 3 through June 12, 1974, during which period Filter 3, 0.8-1.8 Hz was being used.
On the other hand, the number of events included in the summary bulletin shows no second maximum, indicating that the analysts have successfully removed the local events, including the cultural ones, from the event bulletin.

Figure 3 shows the correlation between hourly noise level and hourly number of events in the event bulletin. The correlation seems excellent and a slope of -1.0, which would be appropriate for a seismicity magnitude relationship of $N \sim 10^{-1.0 m_b}$ seems to be a good fit.

In Table I we note the variation in number of DP and EP detections with filter passband. It is not quite clear at present why there should be so much smaller a percentage variation in number of EP events as compared to DP events. One possibility is that the regional events have a steeper frequency-magnitude curve than the teleseismic events and therefore a high percentage of small amplitude, comes from this source. Then a small threshold change at low amplitudes will yield a larger percentage change in number of events than the same change at larger amplitudes.

Another possible contributing explanation is that the different filters introduce different amounts of "ringing" which generate different numbers of "multiple picks" per event. Multiple picks are generally eliminated by the EP processor.

Still another possibility is that some of the DP detections are truly random fluctuations whose number increases as the passband narrows due to instability in the STA, combined with a fixed threshold. This possibility is, however, ruled out by the observed absence of DP detections which appear to be random fluctuations.

The dramatic increase in number of EP processed detections as the filter changes from 0.9-1.8 Hz to 0.8-1.8 Hz is presumably due in part to the simultaneous decrease in the EP threshold from 14 to 12 dB.

The most important result of this study is, however, that when one considers the standard errors of the means of the number of summary detections there is no conclusive relative advantage to the use of any of these filters. If we nonetheless take the apparent advantage in number of summary events produced, 21.4 as compared to 20, 21, or 22, one sees in Table I that this
Figure 3. Published events per hour as a function of the hourly noise level for the period April 3 through June 12, 1974, during which period Filter 3, 0.8-1.8 Hz was being used. The numbers in brackets represent multiple points.
corresponds to a threshold advantage of only 0.03 magnitude units. And we must keep in mind, as mentioned in the Introduction, that the parameters N, N', Q, Q', ΔU and P have not been adjusted for optimum performance with respect to filters other than 0.9-1.4 Hz. Thus even this uncertain small advantage might disappear or be reversed in an optimized system. The difference of 0.03 is much less than the rms noise difference of 0.3. The main reason is presumably that the signal has also been substantially cut down by the tighter filter.

In Table I we see various estimates of percentage efficiency of the system with the different filters. However, in light of the fact that most of the "false alarms" are regional events, the significance of these numbers is questionable. We must first develop an algorithm to eliminate problems due to regional events. Then the threshold may be lowered to begin catching "true" false alarms, and with the "true" false alarm rate held as nearly constant as possible we may compare the number of detected events.

In Figure 4 we see the derivative with respect to magnitude of the logarithm of the cumulative recurrence curves constructed from the summary bulletin for the four different filter time periods. The slope seems to be constant in each case between 4.0 and 4.8 \( m_b \). (The curvature of \( m_b > 4.8 \) suggests that Schlein and Toksoz (1970) were correct in suggesting that a quadratic should be used to fit recurrence curves.) We therefore fit a least-squares line to the recurrence curves in the interval 4.0-4.8 \( m_b \) and estimated the 50% and 90% cumulative threshold. These yield the estimated threshold differences seen in Table I. Subjectively we feel that they are consistent with the more reliable threshold differences determined from the total number of events detected.

Figure 4. Derivative with respect to magnitude of the logarithm of the cumulative recurrence curves constructed from LASA bulletin data in four separate time periods—the interval March 11 through July 25, 1974. A different bandpass filter was used in each of the time periods. Least-squares lines fitted to the recurrence curves in the magnitude interval 4.0–4.8 were used to determine differential detection threshold.
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APPENDIX

Noise level, number of detection processor detections, number of events processed by the event processor and number of events published in the daily event summary bulletin.